The Gas Process Development Unit (GPDU) Team

FY01 TECHNICAL PROGRESS REPORT

TEAM MEMBERS:

Larry Bissett, Jenny Tennant, Susan Shoemaker, Pete Hensel, John Rotunda, Rick Pratt, Carol Utt, Steve Beer, Randy Barnes, Elaine Everitt

DESCRIPTION:

NETL's Gas Process Development Unit incorporates removable spool pieces and unique design features that expand process assessment capabilities.

The Gas Process Development Unit (GPDU) Team is a part of the Separations and Gasification Engineering Division at NETL, and is focused on evaluating processes and sorbents for removal of chemical contaminants from a gasification gas product stream.

Using a 150,000-cubic foot/hour synthesis gas generator at the Gas Process Development Unit[1] in Morgantown, West Virginia, the team will test new, attrition-resistant gas desulfurization sorbents in fluidized-bed and transport-bed reactors to assess their commercial readiness. Working with contractors and industrial partners, researchers will develop information and evaluate processes, sorbents, and catalysts in support of larger-scale testing in other units or in Clean Coal Technology projects.

The conceptual goals for the GPDU are to define a versatile system that will: (1) Fill the gap between small-scale testing and large-scale demonstration projects by providing a cost effective test site for transport and fluid-bed desulfurization reactor and sorbent development; (2) demonstrate sorbent suitability over a wide range of parameters; (3) generate significant information on process control for transport- and fluidized bed-based desulfurization; (4) have process conditions representative of anticipated commercial applications in terms of temperatures, pressures, compositions, velocities, and sorbent cycling; and (5) be configured and sized to produce results scalable to commercial applications.

FY01 RESEARCH OBJECTIVES:

Major construction and instrumenting activities of a 150,000 cubic foot per hour synthesis gas (syngas) generator and a versatile gas process development unit consisting of two fluidized-bed reactors and two transport reactors were completed in FY00, and shakedown activities at the GPDU were initiated. Goals were established at the beginning of FY01 to complete independent shakedown of both units. Specifically, the goals for FY01 were:

- **Complete PDU Shakedown in the Transport Reactor Mode.** In addition to checking the mechanical integrity of the unit, this activity will establish the level of difficulty associated with the operation of two transport reactors linked to provide continuous sorbent absorption-regeneration cycling. Specific shakedown activities planned were: (1) Circulate sorbent with air at ambient temperature, (2) prove safety interlocks, and (3) heat unit as much as possible with the PDU preheaters and circulate sorbent.

- **Obtain Syngas Generator Operating Permit.** NETL employs a safety analysis and review system (SARS) to ensure the safety and readiness for operation of R&D projects. Operating permits are issued when construction has been completed, external ES&H permits are received, a hazard analysis has been conducted, and operating protocols are documented. An operating permit for the GPDU was received in FY00, and the permit for the syngas generator is still required.

- **Complete Syngas Generator Shakedown.** Upon receipt of an operating permit, independent shakedown of the Syngas Generator will check the mechanical integrity and process design of the unit, prove safety interlocks, and demonstrate the range of operability of the unit. A measurement of success will be the ability to generate suitable synthetic syngas using the syngas generator, including adequate sulfuric acid conversion to hydrogen sulfide.

- **Complete training of operations staff needed for integrated operation.** Roughly 14 operations personnel will be required to operate the syngas generator, the GPDU, and the associated subsystems in an integrated fashion. Classroom and on-the-job training is necessary to ensure safe, reliable operations of the facility.

LONG TERM GOALS / RELATIONSHIP TO NETL's PRODUCT LINE(S):

The *Gasification Technologies Program*[2] has a mission to foster the commercialization of gasification-based processes that convert carbonaceous feedstocks to electricity and to steam, fuels, chemicals, and hydrogen. It is envisioned that the program will lead to gasification-based processes that will be ***more attractive economically, have higher availability and thermal efficiencies, and demonstrate superior environmental performance*** compared to competing technologies. Key activities towards accomplishing these goals focuses on improving the economics and performance of advanced gasification processes, development of step-out technologies for maximizing thermal efficiency, minimizing emissions, and concentrating carbon dioxide for eventual disposal or use.

The work at the GPDU will contribute towards those goals in the area of gas cleaning and conditioning. Hot/warm gas desulfurization is an integral step towards achieving the stringent synthesis gas quality requirements for cogeneration/coproduction and fuel cell applications. Hot or warm gas cleanup for the removal of hydrogen sulfide from syngas is being developed as an alternative to cold gas cleanup, because it has a higher thermal efficiency and improved environmental aspects over traditional cold gas cleanup. In the hot (or warm) gas cleanup process, a regenerable solid sorbent is reacted with sulfur-laden synthesis gas where sulfur chemically bonds to the sorbent, resulting in a clean fuel gas. The sulfur-laden sorbent is then fed to a second reactor where it is reacted with oxygen to remove the sulfur. One of the applications of the GPDU is to provide performance testing of sorbents at process conditions typical of a commercial-scale operation. A sorbent's efficiency for removing hydrogen sulfide from a simulated coal gas stream to levels required for downstream processing can be evaluated over many sulfidation-regeneration cycles at this facility.

The GPDU additionally provides the capability to evaluate both fluidized-bed and transport reactor processes. Although it is envisioned that these reactors can be used for other applications, the GPDU will initially be used to demonstrate that continuous sorbent sulfidation and regeneration can be achieved in a two-transport reactor scheme. Because transport reactors operate at higher gas velocities than fluidized beds, the required diameter for a transport reactor is much smaller, which translates to a lower capital cost. Operations protocols for achieving the needed pressure balances and temperature control in a transport reactor system with sorbent circulation and recirculation capabilities – a non-trivial issue – can be established at this facility and applied at a scaled-up facility. Additionally, the sorbent's resistance to attrition and degradation as a result of the cycling and the physical movement of the sorbent through a continuous process can be assessed. An attrition-resistant sorbent will minimize the replacement frequency in a commercial-scale process, which thereby minimizes consumables costs and the amount of spent sorbent that will ultimately be landfilled. The scale of the GPDU is large enough to generate realistic data for predicting performance in a large process, yet small enough to evaluate various sorbents in a manner that is not cost prohibitive.

Additionally, the GPDU supports the U.S. Department of Energy's *Vision 21* [3] initiative, which has a primary goal of ***effectively removing all environmental concerns associated with the use of fossil fuels*** for producing electricity, transportation fuels, and high-value chemicals ***at competitive costs***. The GPDU can be utilized to evaluate new sorbents for capture of undesirable components; this

addresses the program's environmental goals for reducing emissions. The protocols developed to optimize the operations of the different process configurations will provide valuable data that can result in achieving capital and operating cost targets needed for a Vision 21 plant.

Finally, the GPDU offers a test bed for new technologies and approaches (instruments, sorbents, catalysts, processes) that will assure the safe, clean, and affordable use of fossil energy resources. NETL places great emphasis on partnering with industrial, academic, and government stakeholders to create commercially viable technical solutions to energy and environmental problems. Through cooperative research and development agreements, the versatile GPDU provides test and evaluation opportunities to these stakeholders.

SUMMARY ACCOMPLISHMENTS:

The accomplishments of the team in FY01 as related to the stated goals are summarized below:

- **Independent shakedown of the transport mode GPDU was initiated, and significant progress was made towards completing this milestone. Specific activities were:**

1. Sorbent loading
- Successfully loaded sorbent into feed hopper/receiver
- Demonstrated feed hopper/receiver fluidization and inventory check
- Demonstrated operability of feeder and feeder purge
- Demonstrated sorbent convey into regenerator vessel

2. Cold circulation with air
- Demonstrated sorbent fluidization and recirculation on each reactor side (i.e., absorber and regenerator)
- Demonstrated sorbent circulation between absorber and regenerator with simultaneous recirculation to both risers
- Validated procedures for getting the unit up and down with sorbent in it
- Gained initial insight into operating characteristics and control
- Identified problems that will need addressed mechanically and/or operationally

3. Sorbent removal
- Removed as much sorbent as possible from system
- Determined sorbent recovery factor
- Collected samples for size analysis to determine attrition that occurred

4. System heatup with air (no solids)
- Got the unit as hot as practical with preheated air
- Dryed out refractory of fired devices and reactors
- Cured refractory field joints (i.e., flanges) for steam service
- Confirmed process piping thermal expansion design to temperature achieved
- Confirmed reactor refractory integrity and circulation piping thermal design to temperature achieved

- Determined leak tightness at temperature

5. System heatup with steam (no solids)
- Checked for cold spots and condensation problems
- Confirmed heat tracing performance

- **An operating permit was granted for the syngas generator portion of the facility on March 30, 2001.**

- **Independent shakedown of the syngas generator was initiated and significant progress was made towards completing this milestone. Specific activities were:**

1. Initial light-off
- Demonstrated light-off and stable operation of first-stage pilot and axial burner
- Demonstrated governing operational interlocks

2. SGG startup
- Achieved startup temperatures at low pressure
- Proved interlocks governing startup sequence
- Demonstrated operational mode transitions (e.g., combustion mode to syngas mode) at low pressure and safe firing system
- Dryed out SGG combustion vessel refractory

- **Training of operations personnel was initiated and is on-going.** Operations staff levels were gradually increased during the fiscal year to a nearly full complement needed for integrated operations of the syngas generator and the GPDU. The staff has received varying levels of on-the-job and classroom training, proportional to each individual's time at the facility. Training has encompassed the process control system, natural gas compressor operations, reverse osmosis water system operations, flare operations, preheater operations, independent operation of the GPDU, and independent operation of the syngas generator. Training will continue through such time as integrated operation is achieved.

Other significant milestones included:

- **A programmatic and technical merit review was conducted for the purpose of evaluating the GPDU with respect to technology and commercialization potential.** An industry and DOE review team validated that the project was meeting the needs of the DOE programs. The external reviewers agreed that the DOE/NETL GPDU facility is well designed and constructed for its intended purpose of demonstrating deep sulfur removal from synthetically produced syngas using fluid bed or transport reactor modes of solids/gas contact. Additionally, the group recommended that the DOE should continue to provide funding for final checkout and test operation for the GPDU, sufficient to allow limited duration operation at the facility's design operating conditions.

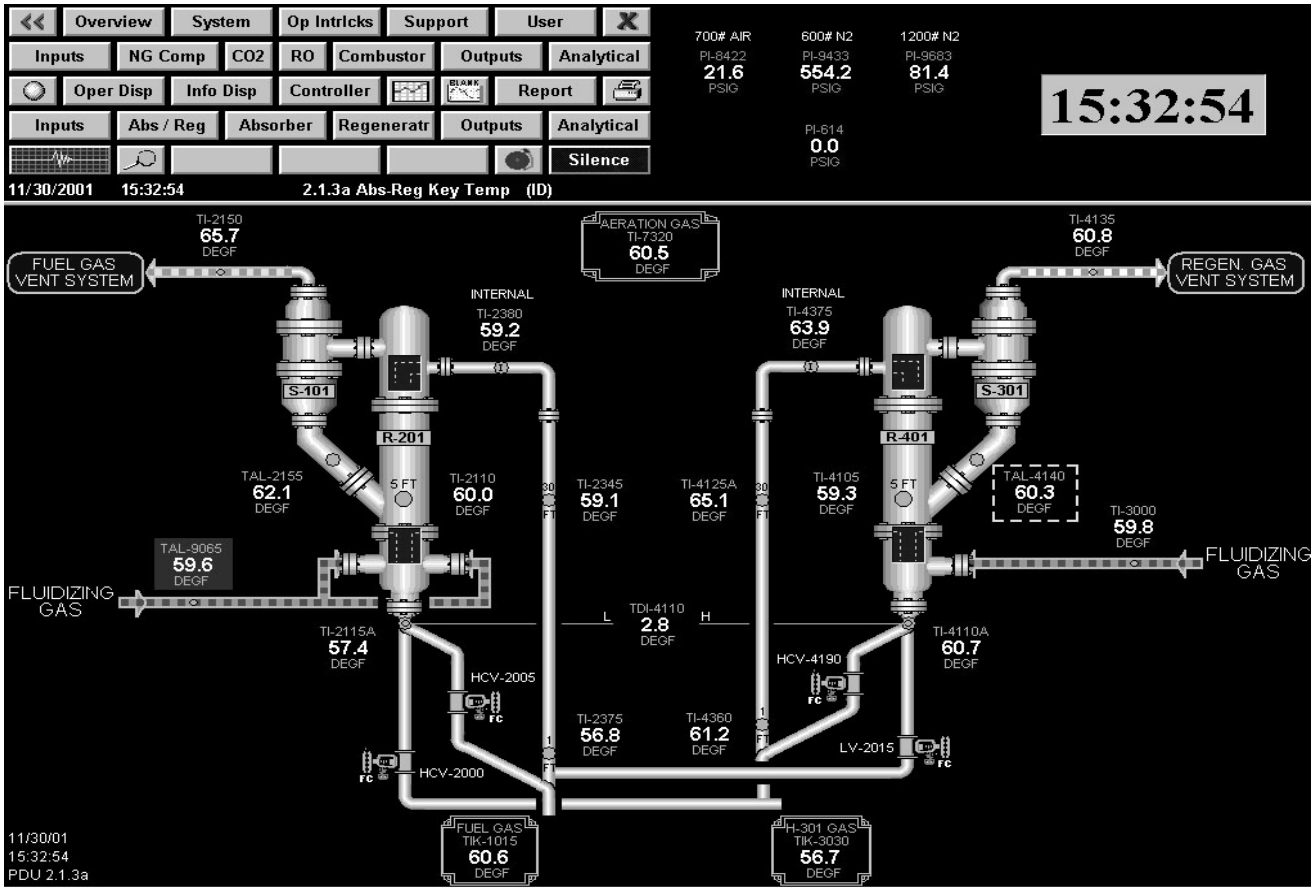
- **SARS Documentation for integrated operation of the GPDU and the syngas generator was completed and presented to the NETL Process Safety Committee.**

- **Design for the analytical system was completed.** This activity included identification of sampling process points, specification and procurement of process and analytical equipment, preparation of an analyzer laboratory to receive equipment, and initiation of installation.

RESULTS: [4]

The GPDU and the coupled syngas generator were taken through significant shakedown activities to verify the system's interlocks and control system. The facility is highly instrumented, with a user-friendly control and data acquisition system, and provides process data that will allow a thorough analysis of operating conditions used to achieve smooth operations and assessment of system performance. The GPDU has eighty-one flow transmitters, fifty-three differential pressure transmitters, twenty-five pressure transmitters, and one hundred thirty one temperature elements.

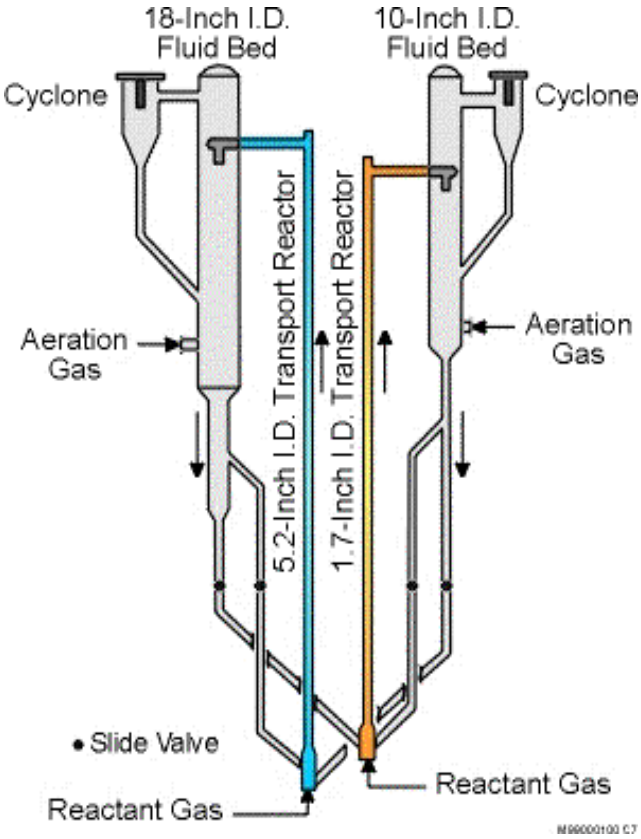
The facility uses a Seimens Energy & Automation, Inc. control system. The hardware is Advanced



Process Automation and Control System (APACS) and the control software is 4-mation. The graphical user interface (GUI), ProcessSuite Vision® software, allows operators to see pertinent data points and to interact/control the project. The same software also logs data at a user-specified

frequency for those data points of interest to the project team. The system was customized by NETL's in-house staff to improve ease of operability of the system and to layout intuitive links to process control screens for various sections of the facility. The effectiveness of the system and ease of use was realized during the operational shakedown activities conducted in FY01.

The mechanical design of the GPDU circulation / recirculation system was validated when successful continuous circulation of sorbent between the transport absorber and transport regenerator, with simultaneous recirculation to both risers, was obtained during initial shakedown operations at the facility. About 2,400 pounds of EX-SO3 sorbent (a zinc titanate sorbent developed by Research Triangle Institute and Intercat Development, Inc.) was loaded into the GPDU and fluidized/circulated/recirculated with air and nitrogen for about 42 hours. Continuous circulation was demonstrated between the absorber and regenerator, with simultaneous recirculation to both risers. Typical gas velocities were around 1 ft/s in the beds and around 15 ft/s in the risers. System pressure was varied from 35 psig to 85 psig. Smooth operations at densities up to about 5 lb/ft^3 in the absorber riser were demonstrated. Some reduction in mean particle size was observed. This initial testing validated the GPDU circulation system design and suggested that no mechanical design changes were needed for continued shakedown.



When operated in the transport reactor operational mode, the facility's fluidized-beds serve as a path for circulation or recirculation of solids.

GPDU heatup (without solids) to nominally 50% of design operating temperature was achieved. The GPDU was heated at pressure using hot air from both fired preheaters in the system. All three primary objectives of the heatup were achieved: 1) dryout of the refractory in the fired devices and reactors, 2) confirmation of reactor refractory integrity and circulation piping thermal design, and 3) confirmation of process piping thermal expansion design. There were no discernable problems during heatup, and mechanical integrity of the system looked good.

Solids were not used in the system for this initial heatup because of refractory dryout considerations. Some approximate process conditions reached during the heatup are as follows:

Reactor pressure: 150 psig
Fuel gas filter inlet: 540 ^{o}F
Absorber refractory: 600-750 ^{o}F
Regeneration gas filter inlet: 545 ^{o}F
Absorber riser: 650-700 ^{o}F
Inert gas preheater outlet: 1000 ^{o}F
Regenerator refractory: 450-750 ^{o}F
Air preheater outlet: 1000 ^{o}F
Regenerator riser: 550-700 ^{o}F

The GPDU was operated with steam (no solids). In a simulation of actual startup, the GPDU was initially heated with hot air from both fired preheaters, and then steam at 850 ^{o}F was phased in. The primary purpose of this successful, short-duration test of steam in the unit was to determine if there are cold spots and condensation problems in the system. This was done without solids in the system to avoid the problems that solids and condensate (if any formed) would cause.

The syngas generator startup operations were demonstrated. The first-stage burner was fired with natural gas and air to dry out refractory in the SGG combustion unit. Through controlled temperature ramps and holds, this culminated in first-stage temperatures of 2000 ^{o}F, third-stage temperatures of 800 ^{o}F, and combustion unit outlet temperatures up to about 1400 ^{o}F. Various process parameters and procedures were investigated to achieve reliable ignition, good flame sustainability, and temperature control. Key aspects of startup were successfully demonstrated.

REFERENCES:

[1] http://www.netl.doe.gov/products/r&d/gaseous/pdu.html

[2] http://www.netl.doe.gov/coalpower/gasification/

[3] http://www.netl.doe.gov/coalpower/vision21/

[4] Bissett, Larry A. (2001). Hot/warm gas cleanup. Poster presented at the Vision 21 Program Review Meeting, U.S. Department of Energy, National Energy Technology Laboratory, Morgantown, West Virginia, November 6-7, 2001.

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Additional information concerning the activities of the Gas Process Development Unit Team is available by contacting Elaine Everitt at (304) 285-4491, Elaine.Everitt@netl.doe.gov.